

# **Washington Department of Fish and Wildlife Lake Roosevelt Pelagic Fish Study, 1998**

Annual Report 1998

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## Abstract

Pelagic fishes, such as kokanee and rainbow trout, provide an important fishery in Lake Roosevelt; however, spawner returns and creel results have been below management goals in recent years. Our objective was to identify factors that potentially limit pelagic fish production in Lake Roosevelt including entrainment, food limitation, piscivory, and other abiotic factors. We estimated the ratio of total fish entrained through Grand Coulee Dam to the pelagic fish abundance for September and October, 1998. If the majority of these fish were pelagic species, then entrainment averaged 10-13% of pelagic fish abundance each month. This rate of entrainment could impose considerable losses to pelagic fish populations on an annual basis. Therefore, estimates of species composition of entrained fish will be important in upcoming years to estimate the proportion of stocked pelagic fish lost through the dam. Food was not limiting for kokanee or rainbow trout populations since growth rates were high, and large zooplankton were present in the reservoir. Estimates of survival for kokanee were low ( $< 0.01$  annual) and unknown for rainbow trout. We estimated that the 1997 standing stock biomass of large ( $>1.1$  mm) *Daphnia* could have supported 0.08 annual survival by kokanee and rainbow trout before fish consumption would have exceeded available biomass during late winter and early spring. Therefore, if recruitment goals are met in the future there may be a bottleneck in food supply for pelagic planktivores. Walleye and northern pikeminnow were the primary piscivores of salmonids in 1996 and 1997. Predation on salmonid prey was rare for rainbow trout and not detected for burbot or smallmouth bass. Northern pikeminnow had the greatest individual potential as a salmonid predator due to their high consumptive demand; however, their overall impact was limited because of their low relative abundance. We modeled the predation impact of 273,524 walleye in 1996, and 39,075 northern pikeminnow in 1997 because diet data revealed predation on salmonids during these years. We could not determine the absolute impact of piscivores on each salmonid species because identification of fish prey was limited to families. Our estimate of salmonid consumption by walleye in 1996 and northern pikeminnow in 1997 shows that losses of stocked kokanee and rainbow trout could be substantial (up to 73% of kokanee) if piscivores were concentrating on one salmonid species, but were most likely lower, assuming predation was spread among kokanee, rainbow trout, and whitefish. Dissolved oxygen was never limiting for kokanee or rainbow trout, but temperatures were up to 6EC above the growth optimum for kokanee from July to September in the upper 33 meters of water. Critical data needed for a more complete analysis in the future include species composition of entrainment estimates, entrainment estimates expanded to include unmonitored turbines, seasonal growth of planktivorous salmonids, species composition of salmonid prey, piscivore diet during hatchery releases of salmonids, and collection of temperature and dissolved oxygen data throughout all depths of the reservoir during warm summer months.

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# Table of Contents

Abstract.....	i
Acknowledgments.....	ii
List of Tables.....	iii
List of Figures.....	iv
1.0 Introduction.....	1
1.1 Project History.....	
1.2 Background Information.....	
1.3 Objectives.....	
2.0 Methods.....	
2.1 Entrainment.....	
2.1.1 Pelagic Fish Abundance and Distribution.....	
2.1.2 Ratio of Entrainment to Pelagic Fish Abundance.....	
2.2 Food Limitation.....	
2.2.1 Kokanee Spawner Length.....	
2.2.2 Availability of Large Zooplankton.....	
2.2.3 Planktivore Consumption Versus Available <i>Daphnia</i> Biomass.....	
2.3 Piscivory of Salmonids.....	
2.3.1 Relative Impact of Piscivore Species and Age Classes.....	
2.3.2 Losses of Juvenile Salmonids to Piscivores.....	
2.4 Temperature and Dissolved Oxygen Limitations.....	
3.0 Results.....	
3.1 Entrainment.....	
3.1.1 Pelagic Fish Abundance and Distribution.....	
3.1.2 Ratio of Entrainment to Pelagic Fish Abundance.....	
3.2 Food Limitation.....	
3.2.1 Kokanee Spawner Length.....	
3.2.2 Availability of Large Zooplankton.....	
3.2.3 Planktivore Consumption Versus Available <i>Daphnia</i> Biomass.....	
3.3 Piscivory of Salmonids.....	
3.3.1 Relative Impact of Piscivore Species and Age Classes.....	
3.3.2 Losses of Juvenile Salmonids to Piscivores.....	
3.4 Temperature and Dissolved Oxygen Limitations.....	
4.0 Discussion.....	
4.1 Entrainment.....	
4.2 Food Limitation.....	
4.3 Piscivory of Salmonids.....	
4.4 Temperature and Dissolved Oxygen Limitations.....	
4.5 Future Data Collection Recommendations.....	
Literature Cited.....	
Appendix A. Pelagic Fish Abundance and Distribution.....	
Appendix B. Bioenergetics Model Inputs.....	

## List of Tables

<u>Table</u>	<u>Page</u>
Table 3.1.0. Reservoir wide abundance estimates for fish captured in the pelagic zone in 1998 ....	
Table 3.2.0. Kokanee spawner lengths from Lake Roosevelt and other lakes and reservoirs in the Northwest.....	
Table 3.2.1. Biomass of edible size (>1.1 mm) <i>Daphnia</i> and the corresponding number of age 1 kokanee or rainbow trout it would take to consume the biomass each month .....	
Table 3.3.0. Estimated losses of kokanee or rainbow trout to walleye in 1996 and northern pikeminnow in 1997 .....	
Table 3.4.0. Temperature and dissolved oxygen results for September and October 1998 .....	

## List of Figures

<u>Figure</u>	<u>Page</u>
Figure 2.1.0. Map of Lake Roosevelt showing the three sampling regions.....	
Figure 3.1.0. Percent frequency of each species by 10 meter depth strata for September and October 1998 .....	
Figure 3.1.1. Length frequencies for acoustic targets and fish captured in gill nets and trawls in the lower region and reservoir wide for September and October 1998.....	
Figure 3.1.2. Hydroacoustic estimate of target density by size and depth for the lower region each month .....	
Figure 3.1.3. Estimated number of fish entrained, and the ratio of September 1996 (□), September 1997 (△), and October both years (·) entrainment to 1998 pelagic fish abundance.....	
Figure 3.1.4. Estimated population size of kokanee after 12 months of fixed mortality from entrainment at the rates estimated from the 1998 population estimate .....	
Figure 3.2.0. Mean length (+ 2 SE) of <i>Daphnia</i> populations in Lake Roosevelt in 1996 and 1997	
Figure 3.2.1. Ratio of combined rainbow trout and kokanee consumption to available <i>Daphnia</i> biomass for <i>Daphnia</i> larger than 1.1 mm with 0.08 annual survival for stocked fish. <i>Daphnia</i> biomass would not have supported fish consumption when the ratio exceeded 1.0 .....	
Figure 3.3.0. Monthly consumption per 1000 walleye and rainbow trout in 1996 and 1997.....	
Figure 3.3.1. Monthly consumption per 1000 northern pikeminnow, burbot, and smallmouth bass in 1997 .....	
Figure 3.3.2. Consumption for each age class of walleye in 1996 .....	
Figure 3.3.3. Consumption for each age class of northern pikeminnow in 1997 .....	

# Introduction

## Project History

The Lake Roosevelt Monitoring/Data Collection Project has been collecting various biotic and abiotic data since 1988 (Cichosz et al. 1997). During this project it became clear that efforts to stock rainbow trout *Oncorhynchus mykiss* and kokanee *O. nerka* into Lake Roosevelt were not meeting the creel and spawner return goals of managers (Keith Underwood, personal communication). Thus, in 1998 Washington Department of Fish and Wildlife (WDFW) incorporated a pelagic sampling regime for Lake Roosevelt to address specific questions regarding limiting factors to pelagic fish populations.

This document reports modeling of historical data collected by Spokane Tribe of Indians (STI), first year progress, and future research needs of this study. Funding for equipment and personnel was not available until mid-July so research could not begin until September. Data requested in Table 2 of the 1998 scope of work was not available from STI, so this report will not cover bioenergetics modeling for 1998. Therefore, this report contains a bioenergetics analysis of 1996 and 1997 data collected by STI and Eastern Washington University (EWU) and a summary of data collected by WDFW in September and October 1998, with recommendations for future data collection needs.

## Background Information

Many factors can contribute to poor survival for fish populations in a reservoir. A complete list of potential factors includes inadequate spawning habitat, poor egg to fry survival, low food supply, high predation, over-exploitation, emigration, entrainment, and unfavorable physiological conditions. The primary management concerns for Lake Roosevelt fisheries are the poor returns of hatchery origin rainbow trout and kokanee to the creel and to hatcheries for egg taking operations; therefore, this study did not address spawning success issues. Likewise we did not address over exploitation because the adult population was not required to reproduce to support future harvests under the current paradigm. Additionally, rainbow trout harvest in 1996 was less than 5% of the four previously stocked year classes indicating that harvest in any one year was a minor cause of mortality to each year class (Cichosz et al. 1997). Likewise, kokanee harvest in 1996 was less than 1% of fish stocked in any one year, again indicating very low exploitation rates (Cichosz et al. 1997).

Entrainment has been identified as a substantial source of lost juvenile fish in many reservoirs (Boreman and Goodyear 1988; Travnichek et al. 1993). Hydroacoustics on dam intakes allows for accurate measurements of total entrainment (Johnson et al. 1994; Ransom and Steig 1994). Several strategies to minimize entrainment have been used including strobe lights, sound impulses, and fish capturing devices (Nemeth and Anderson 1992; Ross et al. 1993; Knudsen et al. 1994). Entrainment is currently being estimated at Grand Coulee Dam with an array of hydroacoustic transducers by the Colville Confederated Tribes (CCT) in corroboration with Biosonics Inc. Entrainment estimates will be particularly useful when compared to pelagic fish abundance estimates from the reservoir. Understanding pelagic fish distribution in Lake

Roosevelt is important if managers want to minimize entrainment by altering hydro operations.

Food limitation and/or competition can limit fish populations in lakes and reservoirs (Schneidervin and Hubert 1987; Griffith 1988; Persson and Grenberg 1990; Tabor et al. 1996). Rainbow trout and kokanee commonly rely on zooplankton, specifically large *Daphnia*, as a major food source in many western lakes and reservoirs (Galbraith 1967; Eggers 1982; Schneidervin and Hubert 1987; Beauchamp 1990; Beauchamp et al. 1995; Paragamian and Bowles 1995; Teucher and Luecke 1996; Luecke and Teuscher 1994; Tabor et al. 1996; Cichosz et al. 1997; Baldwin et al. In Press). When oligotrophic systems such as Lake Roosevelt are artificially supplemented with large numbers of planktivores, there is potential to over exploit zooplankton biomass (Dettmers and Stein 1996). Several approaches have been used to evaluate food limitations in fish populations. Fish expressing slow growth and low relative weight, when compared to a regional standard, were considered food limited in many studies (Wege and Anderson 1978; Murphy et al. 1991; Marwitz and Hubert 1997). Small invertebrate prey size has also been used to indicate food limitation for fish predators (Mills and Forney 1983; Crowder et al. 1987). However, in large reservoirs averages and standards may not apply due to geographic and biological diversity both within and among systems. Bioenergetics models have been applied to fish populations to estimate fish consumption demand, which is compared to forage supply to evaluate the current and potential exploitation of the food resource (Beauchamp et al. 1995; Baldwin et al. In Press). This method allows researchers to evaluate what proportion of available prey biomass is consumed and how much excess biomass is available for increased fish production.

Top predators such as northern pikeminnow *Ptychocheilus oregonensis*, lake trout *Salvelinus namaycush*, and walleye *Stizostedion vitreum* can have a substantial impact on forage fish populations in many systems (Lyons and Magnuson 1987; Rieman et al. 1991; Vigg et al. 1991; Yule and Luecke 1993; Knight and Vondracek 1993). Bioenergetics modeling has proven effective for quantifying the impact of predators on prey populations (Ney 1990; Yule and Luecke 1993; Beauchamp et al. 1995; Hartman and Brandt 1995). The depletion of fish prey is most common for introduced fish assemblages in reservoir settings where draw-down increases vulnerability of prey fish (McMahon and Bennett 1996).

Fish distribution and habitat use are restricted by fixed physiological constraints which limit the geographical distribution of particular species. Fish can cope with suboptimal conditions in certain systems using behavioral adaptations such as occupying thermal refugia or foraging for short periods in lethal environments (Rahel and Nutzman 1994; Snucins and Gunn 1995). It is important to relate fish distribution to the physical and chemical domain in which they are operating to identify spatial or temporal stresses. Conversely, if fish are occupying physical zones which are suboptimal then behavioral mechanisms to maximize feeding or avoid predation may be identified (Clark and Levy 1988; Luecke and Teuscher 1994).

## Objectives

Our main objective was to identify which environmental and biological factors limit pelagic fish production in Lake Roosevelt. The four possible limiting factors examined were entrainment, food limitation, predation, and other abiotic factors (temperature and dissolved oxygen). The

tasks implemented to fulfill our objectives were as follows:

- Task 1. Evaluate losses due to entrainment by comparing pelagic fish abundance and distribution to monthly entrainment estimates through Grand Coulee Dam;
- Task 2. Examine food limitation as a limiting factor by evaluating relative fish growth, prey size, and bioenergetics modeling of planktivore supply versus demand;
- Task 3. Determine losses of juvenile salmonids to various piscivore populations; and
- Task 4. Determine if temperature and dissolved oxygen limit pelagic fish.

# Methods

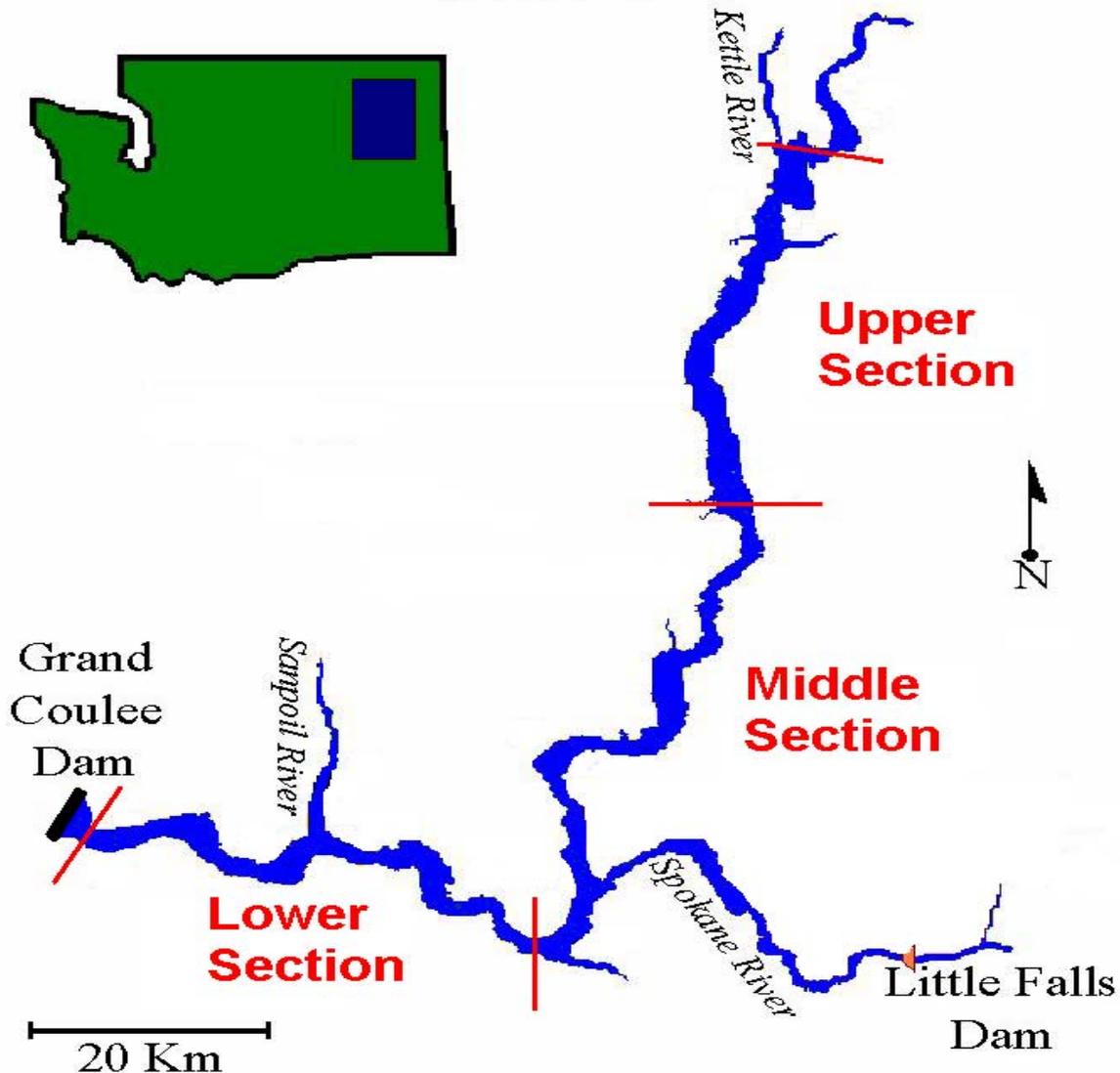
## Entrainment

### Pelagic Fish Abundance and Distribution

We monitored the abundance of various species and size groups of pelagic fish throughout the reservoir to compare to entrainment estimates at the dam and estimate the proportion of pelagic fish entrained. We also examined the distribution of species to identify management strategies to reduce entrainment, if proven significant. Pelagic fish abundance and distribution was determined using a combination of hydroacoustics, gill net, and trawling surveys. Lake Roosevelt was stratified into three regions (upper, middle, and lower) for the surveys that were conducted in September and October 1998 (Figure 2.1.0).

*Hydroacoustic surveys*-We used an HTI model 241 echosounder with a 15Esplit-beam transducer, pole-mounted 1 m below the surface with a down-looking orientation. Data were logged directly into a computer and unprocessed echoes were recorded on digital audio tapes. The pulse repetition rate varied from 3-5 pings/second and only echoes within 7.5Eoff-axis, which met the single echo criteria of the software, were included in the analysis. Each region was sampled on a single night each month, and transects were conducted in an elongated zig-zag pattern across the pelagic zone of each region, near the period of the new moon (Luecke and Wurtsbaugh 1993). Ten transects in each region were originally planned for complete coverage of each region; however, due to time and weather constraints only 3 to 9 transects (usually 8) were completed each night, beginning at the lower end of each region.

# LAKE ROOSEVELT



**Figure 2.1.0.** Map of Lake Roosevelt showing the three sampling regions. Pelagic transects were at least 200 m from shore and deeper than 20 m. Transects were 4-9 km long and lasted 0.5-1 hour with a boat speed of 2-3 m/s. Night transects began at least 0.5 hour after sunset and ended at least 0.5 hour before sunrise.

Each transect was sectioned into 10 m vertical strata from 1 m below the transducer (2 m below the surface) to the bottom of the reservoir. Echo counting was used to determine mean densities for five size classes of acoustic targets (55-45, 45-39.2, 39.2-35.9, 35.9-33.5, and 33.5-28.8 -dB). Target strengths between -55 and -28.8 dB were converted to estimate fish lengths (25-700 mm)

using a formula generated by Love (1971, 1977). Densities were extrapolated to abundance based on mid-month reservoir volumes provided by the Bureau of Reclamation at Grand Coulee Dam.

*Gill netting and trawling surveys*-Gill net and trawl surveys were used to provide species verification and length frequencies of acoustic targets. We set 6 vertical and 3 horizontal gill nets overnight in the pelagic zone of each of the three sections for 1-3 nights following an acoustic survey. Nets were generally placed in the middle third of the shore-to-shore axis and were distributed across several acoustic transects each night. Emphasis was given to areas of high acoustic target abundance. Each vertical gill net was 2.6 m wide, 43 m deep, and consisted of one mesh size throughout (25, 38, 51, 64, 76, or 102 mm stretch). Horizontal nets included 1 floating, 1 mid-water, and 1 bottom net with panels 6 m long, 2.6 m deep, and mesh sizes from 25-102 mm in 13 mm increments.

A monofilament trawl with a 47 m<sup>2</sup> opening was used in each region to actively catch small fish (< 200 mm) which were less susceptible to gill nets. Trawling transects were conducted from September 22-24, and generally overlapped with the lower 4 transects from the hydroacoustic survey in each section. Depths were chosen to maximize catch rates based on target density information from the hydroacoustic surveys; however, the trawl was limited to a maximum depth of 50 m. Trawling tows lasted 1-2 hours and 3-4 tows were conducted each night.

## **Ratio of Entrainment to Pelagic Fish Abundance**

The CCT provided monthly entrainment estimates for monitored turbines of each of the three Grand Coulee Dam powerhouses from January 1996 to August 1998. We extrapolated these numbers to unmonitored turbines within the same powerhouse, then summed across all three powerhouses to estimate total entrainment each month. We then calculated percent entrainment (E/A ratio) by dividing total entrainment by the pelagic fish abundances as described in the Pelagic Fish Abundance and Distribution section. We modeled the E/A ratio over a 12-month period using the average and 95% confidence intervals of September and October E/A values for the pelagic population estimate.

## **Food Limitation**

We used three methods to determine if food limited pelagic fish populations. These included comparing pelagic fish growth in Lake Roosevelt with other systems, monitoring the average size and presence of preferred zooplankton in the lake, and using bioenergetics modeling to compare fish consumption to available zooplankton biomass.

## **Kokanee Spawner Length**

Kokanee spawner length-at-age was compared among Lake Roosevelt and other systems in the Pacific Northwest. Kokanee length-at-age is known to increase with increasing aquatic productivity and/or decreased fish density (Rieman and Myers 1992). We used length-at-age of mature kokanee as an indicator of adequate available forage.

## Availability of Large Zooplankton

Zooplankton species and size data were provided by STI and collected according to the methods of Cichosz et al. 1997. We examined the availability of large *Daphnia* throughout various seasons in 1996 and 1997 to determine if this highly preferred prey item was present, and if the average size was in the preferred range for salmonid planktivores.

## Planktivore Consumption Versus Available *Daphnia* Biomass

We estimated the monthly standing stock biomass of edible *Daphnia*, then determined the number of kokanee or rainbow trout which could have been supported by that biomass.

*Available Zooplankton Biomass*-Edible zooplankton biomass was estimated by reducing the mean monthly *Daphnia sp.* densities by the percent frequency of *Daphnia* larger than 1.1 mm (the smallest size *Daphnia* observed in the diet of salmonids in Lake Roosevelt; STI, unpublished data). This density was then multiplied by the weighted mean weight of *Daphnia* larger than 1.1 mm and the total active volume of the reservoir. The preferred size *Daphnia* (>1.1 mm) was consistent with other systems where salmonids were preying upon abundant zooplankton (Galbraith 1967; Schneidervin and Hubert 1987; and Tabor et al. 1996).

*Planktivore Consumption*-The Wisconsin bioenergetics model (Hanson et al. 1997) was used to generate monthly consumption of zooplankton by stocked kokanee and rainbow trout. Consumption estimates from kokanee and rainbow trout were compared on a gram to gram basis with available zooplankton forage each month and expressed as the C/B ratio where C = consumption and B = biomass. Model inputs for each fish species included diet, growth, thermal experience, and abundance. Literature values provided in the model were used for prey caloric densities (Hanson et al. 1997).

*Diet*-We modeled the average wet weight proportions of each diet item or group. Diet items were categorized into *Daphnia*, *Leptodora*, Copepods, Insects, or Other. STI diet analysis calculated the dry weight proportion of each diet item so a dry to wet weight conversion was used (Hanson et al. 1997). See Cichosz et al. 1997 for a detailed description of diet analysis procedures.

*Growth*-Growth was estimated on an annual basis from scale annuli. A weight-at-age regression was generated for each species to estimate the weight of age classes which were not sampled in the scale analysis (Appendix B).

*Thermal Experience*-Thermal experience was estimated from available water temperatures measured by the STI during biweekly or monthly water quality sampling. We assumed fish were occupying their optimal temperature zone for growth because we did not have species and size specific distribution.

*Abundance of Planktivores*-Kokanee and rainbow trout stocking numbers were obtained from the Lake Roosevelt Net Pen Program and Sherman Creek Hatchery. We modeled stocked salmonids beginning on their day of release from the net pens. In 1996, we modeled a kokanee population

of 278,756 age 1 and 50,899 fry, along with 576,853 age 1 rainbow trout. In 1997, we modeled 265,396 age 1 kokanee and 488,290 age 1 rainbow trout. Survival was unknown, so we estimated the maximum survival rate where fish consumption would not exceed *Daphnia* biomass during any one month. Age 1 kokanee and rainbow trout which survived 1996 were carried over into 1997 and modeled as age 2. The annual survival rate was modeled on a monthly basis using the equation:

$$N_t = N_{t-1} * e^{-z_t}$$

where  $N_t$  = the abundance at time  $t$ ,  $N_{t-1}$  = the abundance at time  $t-1$ , and  $z$  = natural log of survival. Monthly zooplankton density and size structure was not available from STI for 1998 at the time of this report, therefore, we will not model monthly consumption of net pen released kokanee and rainbow trout for 1998 until next year.

## **Piscivory of Salmonids**

We used the Wisconsin (Hanson et al. 1997) bioenergetics model to compare monthly consumption of prey fish by specific size classes of piscivores (e.g., walleye, burbot, northern pikeminnow, smallmouth bass, and rainbow trout) to the number of kokanee and rainbow trout stocked. Model inputs for each fish species included diet, growth, thermal experience, abundance, and spawning (day of year and percent of body weight spawned). Literature values provided in the model were used for prey caloric densities and dry to wet weight stomach content conversions for each prey type in the diet analysis (Hanson et al. 1997). We used weight-at-age data from Kirillov (1988) for burbot growth because no scale or otolith analysis was available and length frequencies were similar between Lake Roosevelt and Vilyuysk Reservoir.

## **Relative Impact of Piscivore Species and Age Classes**

We identified which species and age class had the greatest potential for impact on recruiting salmonids and estimated monthly consumption to identify the season(s) when piscivory was highest. Abundance estimates for rainbow trout (age 2 and older), burbot, northern pikeminnow, and smallmouth bass were not available; therefore, we used a bioenergetics model to generate consumption estimates per 1000 piscivores of the observed age frequency to facilitate relative comparisons among these species. Age-specific consumption estimates were adjusted to their relative frequency from the gill net and electroshocking surveys. Sample sizes were too small to facilitate age specific diet, so the average diet of all fish age 2 and older was used for each species.

## **Losses of Juvenile Salmonids to Piscivores**

We estimated total consumption by piscivores of salmonids; however, salmonids were not identified to species in the diet analysis. Therefore, we could only estimate a range of impacts on kokanee, rainbow trout, or whitefish, depending on their actual composition in the diet. Evaluating impacts through modeling predation rates depended on an abundance estimate made by EWU for walleye from a Schnabel population estimate for individual sampling sites expanded to reservoir area (McLellan et al. 1998). This population estimate was also applied to 1996

walleye data, but was adjusted for the relative catch per unit effort and size structure among years. Abundance for other piscivore species which had preyed upon salmonids was estimated based on their catch frequency in relation to walleye. We modeled a population of 273,524 walleye in 1996 and 39,075 northern pikeminnow in 1997. Grams of salmonid prey consumed were converted to numerical losses based on the size at stocking and the observed growth rate of juvenile fish. Numerical losses were estimated each month, from May to December, and expressed as a percentage of the original number stocked.

## **Temperature and Dissolved Oxygen Limitations**

We evaluated potential temperature and dissolved oxygen limitations to pelagic fish production using water quality data obtained biweekly by the STI. We then identified areas of suboptimal conditions based on literature values for each species. Temperature and dissolved oxygen profiles were compared to the observed distribution of each fish species and size class obtained from the hydroacoustic and netting surveys to assess the extent of fish occupation in these zones. Finally, the monthly growth rates of pelagic fish were examined to identify periods of low or poor growth which could be linked to above optimal temperatures.

# Results

## Entrainment

### Pelagic Fish Abundance and Distribution

*September*-Reservoir-wide pelagic fish abundance for fish with an acoustic target strength higher than -55 dB (~30 mm) was 590,215(mean) + 224,941 (95% CI). Fish smaller than 100 mm were predominately sculpin (79%); and those from 100-200 mm were mostly whitefish (45%) and longnose sucker (27%) that were captured when the mid-water trawl was sampling near the bottom in the upper region. Kokanee were the most common fish captured between 200-300 mm (71%) and 300-400 mm (39%) whereas whitefish were the major species larger than 400 mm (54%)(Appendix A). Table 3.1.0 shows species-specific abundance estimates when these proportions were applied to the acoustic abundance estimates.

In September, kokanee generally associated with the deepest areas within each region. The lower region provided 72% of all kokanee captured in September and aggregations of fish, presumably all kokanee, were seen on the echosounder near the bottom of the old river channel at depths exceeding 100 m (Figure 3.1.0)(Appendix A). Rainbow trout had a bimodal distribution with one peak near the surface and another from 30-40 m; whitefish and walleye were captured most frequently from 20-50 m (Figure 3.1.0).

*October*-Reservoir-wide pelagic fish abundance for fish with an acoustic target strength higher than -55 dB (~30 mm) was 462,255 (+ 145,107). No trawling was conducted in October so species composition for fish smaller than 200 mm were not reliable due to small sample size (n=3) (Appendix A). Kokanee and whitefish were the most common fish captured larger than 200 mm with the same trend as in September (Appendix A). Table 3.1.0 shows species-specific abundance estimates when these proportions were applied to the acoustic abundance estimates. In October, kokanee were more widely distributed than in September with modes near the surface (20%) and at 50 m (40%) (Figure 3.1.0). Most kokanee were captured in the middle region (58%) in October and the lower region produced 30% of the kokanee catch. Rainbow trout were only caught near the surface in October and whitefish and walleye were captured throughout the water column with a mode between 30-40 m (Figure 3.1.0).

The length frequency of fish captured in nets and trawls was higher than those observed from the acoustic surveys, particularly in the lower region (Figure 3.1.1). All size classes of fish from the acoustic survey of the lower region overlapped with turbine depth; however, the modes in vertical distribution were generally above and below powerhouse depth (Figure 3.1.2).

**Table 3.1.0.** Reservoir wide abundance estimates for fish captured in the pelagic zone in 1998. Estimates represent the percent composition of each species within each size class (Appendix A) multiplied by acoustic target abundances. Species-specific estimates were only made for kokanee, rainbow trout, walleye, and lake whitefish. (\*) indicates fish captured but no estimate due to small sample size.

	September					Total
	<u>Length (mm)</u>					
	25-100	100-200	200-300	300-400	400-700	
All Fish	344,644	125,989	53,745	32,708	33,128	590,215
95% CI	151,333	47,992	18,774	15,162	14,137	224,941
Burbot	-	*	-	-	-	*
Crappie	-	-	-	-	-	-
Chinook	-	-	-	-	-	-
Kokanee	-	-	37,938	12,799	7,645	58,382
Largescale Sucker	-	*	*	-	*	*
Longnose Sucker	-	-	-	-	-	-
N. Pikeminnow	-	-	-	-	*	*
Peamouth	-	*	-	-	-	*
Rainbow Trout	-	-	3,161	4,266	1,274	8,702
Sculpin	*	-	-	-	-	*
Smallmouth Bass	-	-	-	-	-	-
Sturgeon	-	-	-	-	-	-
Walleye	18,139	11,454	9,484	5,688	1,274	46,040
Lake Whitefish	-	57,268	-	9,955	17,838	85,061
Yellow Perch	*	-	-	-	-	*

	October					Total
	25-100	100-200	200-300	300-400	400-700	
All Fish	215,744	98,806	58,349	38,448	50,907	462,255
95% CI	94,395	34,603	14,344	9,627	19,065	145,107
Burbot	-	-	-	-	-	-
Chinook	*	-	-	*	-	*
Crappie	-	*	-	-	-	-
Kokanee	-	-	33,342	19,224	8,038	60,604
Largescale Sucker	-	-	-	-	-	-
Longnose Sucker	-	*	-	-	-	-
N. Pikeminnow	-	-	*	-	*	*
Peamouth	-	-	-	-	-	-
Rainbow Trout	-	-	-	6,152	-	6,152
Sculpin	-	-	-	-	-	-
Smallmouth Bass	-	-	-	-	-	-
Sturgeon	-	-	-	-	-	-
Walleye	-	-	2,779	4,614	8,038	15,430
Lake Whitefish	-	-	19,450	7,690	29,473	56,612
Yellow Perch	-	-	-	-	-	-

## Ratio of Entrainment to Pelagic Fish Abundance

The entrainment to abundance ratio (E/A) ranged from a low of 0.02 (14,277:590,215) in September 1997 to a high of 0.17 (103,153:590,215) in September 1996, but averaged 0.10 for September and 0.13 for October (Figure 3.1.3). However, if the lower 95% confidence limit was used instead of the mean to represent a worst case scenario, then entrainment in September could have been 28% of the total pelagic fish population (E/A = 103,153/365,274). When modeled for 12 months, a starting population of 60,000 age 1-3 kokanee (see Table 3.1.0) would be reduced to 1,100 fish given an entrainment rate of 0.28/month, but only 47,000 fish with an entrainment rate of 0.02/month. (Figure 3.1.4).

## Food Limitation

### Kokanee Spawner Length

We compared the length of age 2 and 3 kokanee spawners in Lake Roosevelt to 11 other lakes and reservoirs in the inland Pacific Northwest (Table 3.2.0). From 1996 to 1998, age 2 spawners in Lake Roosevelt averaged 305 mm, 47 mm longer than in Stevens Lake, the only other lake which reported age 2 spawners. From 1996 to 1998, age 3 spawners in Lake Roosevelt averaged 394 mm, 139 mm longer than the average age 3 spawner from Lake Kootenay, Upper Arrow Lake, Deer Lake, and Loon Lake. No age 4 spawners have been reported in Lake Roosevelt, whereas 6 of the 11 lakes in our comparison reported age 4 spawners.

**Table 3.2.0.** The mean length-at-age for spawning kokanee in Lake Roosevelt and other Pacific Northwest systems (Lake Kootenay, Upper Arrow Lake, Lake Coeur D'Alene, Dhorshak Reservoir, Flathead Lake, Odell Lake, Lake Stevens, Dillon Lake, Granby Lake, Deer Lake and Loon Lake). Data taken from Rieman, B.E. and Deborah L. Meyers. 1991. Kokanee population dynamics. Idaho Department of Fish and Game job completion report. Project F-73-R-13 and Pfeifer, R.L. 1988. Evaluation of the natural reproduction of kokanee (*Oncorhynchus nerka*) in Lake Stevens, Washington as related to the lake limnology and basin.

	Dates	Kokanee Spawner Age		
		2	3	4
Lake Roosevelt	1996-1998	305 + 12 SD	394 + 61 SD	na
Other Lakes	1985-1991	na	255 + 55 SD	320 + 74 SD

### Availability of Large Zooplankton

The average length of *Daphnia* in Lake Roosevelt ranged from 1.1-1.4 mm (depending on month), a size which kokanee and rainbow trout readily consume in many systems (Figure 3.2.0)(Galbraith 1967; Schneidervin and Hubert 1987; Baldwin 1998). Large (>2 mm) *Daphnia* were present in the reservoir during all months in 1997 (Cichosz et al. 1999).

### Planktivore Consumption Versus Available *Daphnia* Biomass

The standing stock biomass of *Daphnia* > 1.1 mm peaked from August to October (4-6 million kg) and was at its lowest in March (140-820 thousand kg). The variance of monthly *Daphnia* densities were high, the coefficient of variation ranged from 0.19-0.73 for 1996 (mean = 0.42 +

0.18 SD) and 0.24-0.90 (mean = 0.50 + 0.26 SD) for 1997. The estimated *Daphnia* biomass available during summer and fall months could have supported 1-61 million rainbow trout or kokanee, but less than 350,000 fish in March (Table 3.2.1). With a return of 527 age 2 spawners kokanee survival was estimated as 0.002 between May 1996 and September 1997 (Tilson et al. 1998); however, we predicted a possible survival rate of 0.08 before fish consumption would have exceeded available biomass ( $C/B > 1.0$ )(Figure 3.2.1).

## Piscivory of Salmonids

### Relative Impact of Piscivore Species and Age Classes

Walleye, northern pikeminnow, and rainbow trout were the only predators that consumed salmonids during the study period (Figures 3.3.0, 3.3.1). However, we excluded rainbow trout piscivores from our analysis because only one had consumed a salmonid. Walleye were the only piscivore examined in 1996, so no comparisons could be made among piscivore species.

*Walleye*-Walleye consumed salmonids in 1996 (n=121), but not in 1997 (n=100). Salmonids comprised 8% (May), 20% (July), and 10% (October) of the diet of walleye over 200 mm TL. From May to December 1996, 151 kg of salmonid prey were consumed per 1000 walleye age 2 and older. Age 4 [437 mm (mean) + 48 (SD)] walleye had the highest salmonid consumption (Figure 3.3.2). Walleye consumption of salmonids peaked in July and August, corresponding to increased diet proportions and preferred water temperatures (Figure 3.3.0).

*Northern pikeminnow*-Northern pikeminnow were the only piscivore which consumed salmonids in 1997 (except one rainbow trout predator). Salmonids comprised 17% of northern pikeminnow's annual diet in 1997, the first year of diet analysis for this species. From May to December 1997, 478 kg of salmonid were consumed per 1000 northern pikeminnow age 2 and older. Age 5 [490 mm (mean) + 62 (SD)] northern pikeminnow had the highest salmonid consumption (Figure 3.3.3). Sample size was not large enough (n=21) to determine seasonal variation; however, pikeminnow consumption peaked in August and September, corresponding to temperatures in their preferred range (Figure 3.3.1).

**Table 3.2.1.** Biomass of edible size (>1.1 mm) *Daphnia* and the corresponding number of age 1 kokanee or rainbow trout required to consume the biomass each month.

	1996			1997		
	<i>Daphnia</i> Biomass (g)	Kokanee	Rainbow	<i>Daphnia</i> Biomass (g)	Kokanee	Rainbow
Jan				7.97E+07	5,824,200	3,425,178
Feb				1.28E+07	835,716	649,774
Mar	1.41E+05			8.22E+06	336,200	253,908
Apr	7.36E+05			2.19E+07	640,151	504,788
May	1.44E+07	206,518	2,933,330	3.14E+08	6,012,673	4,459,566
Jun	1.90E+08	2,491,739	6,894,630	6.40E+07	1,001,969	846,684
Jul	1.59E+09	18,818,567	26,530,616	1.31E+09	16,850,230	14,166,291
Aug	4.16E+09	45,944,548	52,219,467	4.60E+09	53,905,075	45,073,209
Sep	5.73E+09	60,803,685	59,698,942	3.68E+09	44,123,471	20,335,081
Oct	6.28E+09	61,204,458	54,700,681	1.04E+09	11,686,330	3,907,117
Nov	1.33E+09	12,973,341	14,593,233			

Dec	2.31E+09	24,418,523	53,449,277	1.56E+08	1,792,667	1,480,128
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## **Losses of Juvenile Salmonids to Piscivores**

We could not determine the absolute impact of piscivores on each salmonid species because identification of fish prey was limited to families. Our estimate of salmonid consumption by walleye in 1996 and northern pikeminnow in 1997 shows that losses of stocked kokanee and rainbow trout could be substantial (up to 73% of kokanee) if piscivores were concentrating on one salmonid species, but were most likely low-moderate (< 24 %) if the predation was spread among kokanee, rainbow trout, and whitefish (Table 3.3.0).

## **Temperature and Dissolved Oxygen Limitations**

We found no dissolved oxygen limitations for pelagic fish in Lake Roosevelt during 1996 or 1997, however, available data only covered 1/2 to 1/3 of the water column for many of the sampling sites. In contrast, water temperatures were above the growth optimum for kokanee (13EC) throughout the upper 33 m of water from July through September for most sampling sites in 1996 and 1997. The bioenergetics model predicted maintenance or negative growth rates in September 1997 for age 3 kokanee, indicating a potential period of late summer temperature stress. However, 1998 hydroacoustic and gill net surveys indicated that kokanee were behaviorally thermo regulating by occupying depths down to 100 m where temperatures were more favorable (Table 3.4.0)(Appendix A). Water temperatures were more favorable for rainbow trout, only exceeding 18EC (rainbow trout optimum) in the top 10 m during July through September except at Spring Canyon and Keller Ferry, where warmer temperatures extended to 20 m depth.

**Table 3.3.0.** Estimated losses of kokanee or rainbow trout to walleye in 1996 and northern pikeminnow in 1997. The 1997 walleye population estimate was adjusted to the relative CPUE among years. The northern pikeminnow population was based on relative abundance to walleye (1:7). The percent of total stocked for each species represents the maximum losses assuming 100% of the salmonid proportion of the predators diet was that species.

273,524 Walleye 1996								
	Month	#/lb	(mm) Length	(g) Weight	% of Predator Population	Mass (g) Consumed	Maximum Number Consumed	Maximum % of Total Stocked
Consumption of Kokanee Prey	May	14	149	32	0.42	2,683,958	34,924	0.11
	Jun	12	157	38	0.39	5,235,996	54,303	0.16
	Jul	10	166	45	0.35	8,124,938	63,610	0.19
	Aug	8	180	57	0.32	7,581,679	43,155	0.13
	Sep	7	188	64	0.23	6,133,066	22,431	0.07
	Oct	6	198	75	0.19	4,930,873	12,419	0.04
	Nov	5	210	90	0.14	4,005,800	6,396	0.02
	Dec	4	225	112	0.10	2,689,854	2,457	0.01
<b>Total</b>						<b>239,695</b>	<b>0.73</b>	
Consumption of Rainbow trout Prey	May	6	190	75	0.20	2,683,958	7,277	0.01
	Jun	5.5	195	82	0.19	5,235,996	12,061	0.02
	Jul	5	202	92	0.16	8,124,938	14,288	0.02
	Aug	4.5	208	100	0.14	7,581,679	10,896	0.02
	Sep	4	217	113	0.12	6,133,066	6,271	0.01
	Oct	3.5	227	130	0.10	4,930,873	3,880	0.01
	Nov	3	239	151	0.06	4,005,800	1,615	0.00
	Dec	2.5	255	180	0.04	2,689,854	584	0.00
<b>Total</b>						<b>56,872</b>	<b>0.10</b>	
39,075 Northern pikeminnow 1997								
Consumption of Kokanee Prey	May	14	149	32	0.42	829,203	10,790	0.03
	Jun	12	157	38	0.39	2,117,211	21,958	0.07
	Jul	10	166	45	0.35	3,256,832	25,498	0.08
	Aug	8	180	57	0.32	3,776,063	21,493	0.07
	Sep	7	188	64	0.23	3,908,319	14,294	0.04
	Oct	6	198	75	0.19	3,641,456	9,171	0.03
	Nov	5	210	90	0.14	1,022,302	1,632	0.00
	Dec	4	225	112	0.10	123,429	113	0.00
<b>Total</b>						<b>104,949</b>	<b>0.32</b>	
Consumption of Rainbow trout Prey	May	6	190	75	0.20	829,203	2,248	0.01
	Jun	5.5	195	82	0.19	2,117,211	4,877	0.01
	Jul	5	202	92	0.16	3,256,832	5,727	0.02
	Aug	4.5	208	100	0.14	3,776,063	5,427	0.02
	Sep	4	217	113	0.12	3,908,319	3,996	0.01
	Oct	3.5	227	130	0.10	3,641,456	2,865	0.01
	Nov	3	239	151	0.06	1,022,302	412	0.00
	Dec	2.5	255	180	0.04	123,429	27	0.00
<b>Total</b>						<b>25,580</b>	<b>0.08</b>	

**Table 3.4.0.** Temperature and dissolved oxygen during September and October 1998. Depths from 0-33 m are an average of all 9 STI sampling locations. Temperature and DO levels which were above optimal for kokanee are indicated by a (\*) and both kokanee and rainbow trout by an (\*\*).

Depth (m)	Temperature (EC)					Dissolved Oxygen (mg/L)				
	10-Sep	15-Sep	23-Sep	7-Oct	27-Oct	10-Sep	15-Sep	23-Sep	7-Oct	27-Oct
0	**20.8	**21.4	**19.5	*17.4	15.2	8.4	8.2	8.0	8.3	8.7
3	**20.8	**20.7	**19.7	*18.1	15.2	8.4	8.1	8.0	8.1	8.5
6	**20.6	**20.7	**19.6	*18.1	15.1	8.3	8.0	8.0	8.1	8.4
9	**20.6	**20.7	**19.6	*18.1	15.1	8.3	7.5	7.9	8.0	8.4
12	**20.5	**20.6	**19.6	*18.1	15.1	8.2	7.1	7.9	8.0	8.4
15	**20.4	**20.5	**19.6	*18.1	15.1	8.1	6.8	7.9	8.0	8.4
18	**20.2	**20.5	**19.6	*18.1	15.1	8.0	6.7	7.8	8.0	8.4
21	**20.1	**20.4	**19.5	*18.1	15.0	7.9	6.6	7.8	7.9	8.3
24	**20.0	**20.2	**19.4	*18.2	15.0	7.8	6.4	7.7	7.9	8.3
27	**19.9		**19.2	*18.1	15.2	7.8		7.7	7.8	8.2
30	**19.7	**20.5	**19.2	*18.1	15.1	7.4	7.4	7.6	7.8	8.2
33	**19.4		**19.2	*18.1	15.1	6.8		7.4	7.8	8.2
40		**20.2					7.3			
50		*19.9	**19.3	*18.6	*17.3		7.0	7.3	7.6	7.6
60		*19.7					7.0			
70		*19.6					6.9			
72				*18.3					7.5	
75			**19.2					7.4		
80		*19.5		*18.5			6.8		7.3	
85				*18.5					7.3	
90		16.6					6.6			
98					*17.0					7.4
100			*17.6					5.5		

# Discussion

## Entrainment

Entrainment had high potential to limit pelagic fish production in Lake Roosevelt, although we could not directly measure the loss of pelagic fish because we did not know the contribution of littoral fish to total entrainment. Assuming pelagic fish were most vulnerable to entrainment, we estimated that 2-28% of the pelagic fish population may be lost each month, resulting in a 22-99% reduction of the fish population over 12 months.

We recommend several improvements of data collection and analysis to better understand the impacts of entrainment in the future. Our analysis was limited to September and October 1998; however, it will be important in the future to compare entrainment to the abundance of pelagic fish throughout the year to determine seasonal variation. Species identification of entrained fish is essential for determining the contribution of littoral versus pelagic fish. Because the majority of net pen and hatchery released fish are larger than 150 mm it would also be beneficial to quantify fish entrainment for fish larger than 150 mm. Finally, it will be important to expand the entrainment estimate to unmonitored turbines to completely analyze the variance and potential impact of entrainment.

## Food Limitation

Food was not a limiting factor for pelagic salmonids based on their high growth rates, early maturity, and the presence of large zooplankton throughout the year. Although large *Daphnia* were present in the reservoir, densities were low ( $< 1/L$ ) indicating that zooplankton biomass was limited by low temperatures, phytoplankton productivity, and high flows, rather than zooplanktivory by fish (Brooks and Dodson 1965; Galbraith 1967).

Bioenergetics modeling indicated that the standing stock biomass of *Daphnia* could have supported consumption by an additional 200,000-61 million salmonids in 1996 and 1997, depending on season. Without accounting for *Daphnia* production, survival of net pen and hatchery released salmonids could have increased to 0.08 before planktivore consumption would have exceeded *Daphnia* biomass in late winter. Therefore, if survival increases in the future, a seasonal bottleneck in the availability of large zooplankton may occur during late winter and early spring.

In the future, it will be important to examine the size *Daphnia* selected by planktivores in the winter to obtain diet proportions for modeling and to determine if fish are forced to consume smaller *Daphnia* when zooplankton densities are low. The creel indicated that most salmonids were caught in the lower region of the reservoir during winter months and zooplankton densities were somewhat higher in the lower region as well (Cichosz et al. 1997, 1998). Therefore, a reservoir-wide comparison of *Daphnia* biomass to fish consumption may not be appropriate during winter and estimates of C/B subdivided by reservoir region may better identify forage availability. Additionally, estimates of *Daphnia* production will be necessary to account for all zooplankton biomass available to fish. Finally, if seasonal growth of planktivores can be determined, we can adjust growth rates in the bioenergetics model and obtain more accurate

consumption estimates.

## **Piscivory of Salmonids**

Piscivory of salmonids could account for up to 73% of hatchery releases, depending on the proportion of kokanee, rainbow trout, and whitefish in the diet of piscivores. Walleye and northern pikeminnow were the primary piscivores of salmonids. Walleye had the greatest potential to limit salmonid recruitment due to their high abundance, however, their diet was inconsistent between years so their impact varied.

In the future, it will be important to determine the species composition of the salmonid fraction of each predators diet because it is not known to what extent whitefish contribute. It is possible that piscivores in Lake Roosevelt could concentrate on kokanee and rainbow trout during hatchery and net pen releases, as they did on John Day Reservoir during smolt migration and on rainbow trout fingerlings in central Wyoming reservoirs (McMillan 1984, cited from McMahon and Bennett 1996), thereby increasing total consumption and elevating their overall impact. Therefore, future studies should address short-term losses of stocked fish to more accurately assess the annual impact of piscivores on kokanee and rainbow trout.

## **Temperature and Dissolved Oxygen Limitations**

Temperature and dissolved oxygen did not limit kokanee and rainbow trout. Temperatures above the growth and/or consumption optimum may have forced fish into deeper water, but we were not able to identify negative impacts of this change in distribution. In fact, salmonids can increase their growth rate by moving between optimal and sub-optimal temperature regimes, depending on the availability of forage (Biette and Geen 1980). If growth rates or available forage decrease in the future, we may want to reconsider temperature and other abiotic environmental conditions as possible limiting factors to pelagic fish production.

In the future, it will be important for the Lake Roosevelt Monitoring Program to collect temperature data at various sites to the bottom of the reservoir, as they did in September and October of 1998. This will provide valuable thermal experience data for bioenergetics modeling because fish were distributed much deeper than the standard sampling depths.

## **Future Data Collection Recommendations**

To better understand the impact of these limiting factors in the future we suggest:

- 1) Monitoring the entrainment to pelagic fish abundance ratio during other months/seasons;
- 2) CCT and/or subcontractor provide size specific entrainment estimates to facilitate evaluation of losses of net pen fish (at least separate age-0 fish (<150 mm) from age-1 and older fish);
- 3) CCT and/or subcontractor to provide total entrainment estimates expanded to unmonitored turbines;
- 4) CCT and/or subcontractor provide 95% confidence intervals (or some measure of

- error) around entrainment estimates each month;
- 5) Obtain size and species composition on entrained fish targets at Grand Coulee Dam;
  - 6) Estimate growth of each age class in the spring and fall to bracket summer and winter growth;
  - 7) Identifying salmonid species within the diets of piscivores;
  - 8) Evaluate consumption of rainbow trout and kokanee during net pen or hatchery releases;
  - 9) Determining winter diets and distribution of planktivores; and
  - 10) Collect temperature and dissolved oxygen data throughout all depths of the reservoir from August 1 through September 30.

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## Appendix A

### Pelagic Fish Abundance and Distribution

**Table A.1.** Species composition for size classes of pelagic fish caught in September and October 1998.

Species	September Length (mm)					all sizes
	25-100	100-200	200-300	300-400	400-700	
n=	19	11	17	23	26	96
Burbot	0%	9%	0%	0%	0%	1%
Chinook	0%	0%	0%	0%	0%	0%
Crappie	0%	0%	0%	0%	0%	0%
Kokanee	0%	0%	71%	39%	23%	45%
Longnose Sucker	0%	27%	6%	0%	12%	6%
Largescale Sucker	0%	0%	0%	0%	0%	0%
N. Pikeminnow	0%	0%	0%	0%	4%	1%
Peamouth	0%	9%	0%	0%	0%	1%
Rainbow Trout	0%	0%	6%	13%	4%	4%
Sculpin	79%	0%	0%	0%	0%	14%
Smallmouth Bass	0%	0%	0%	0%	0%	0%
Sturgeon	0%	0%	0%	0%	0%	0%
Walleye	5%	9%	18%	17%	4%	8%
Lake Whitefish	0%	45%	0%	30%	54%	17%
Yellow Perch	16%	0%	0%	0%	0%	3%

Species	October Length (mm)					all sizes
	25-100	100-200	200-300	300-400	400-700	
n=	1	2	21	50	19	93
Burbot	0%	0%	0%	0%	0%	0%
Chinook	100%	0%	0%	2%	0%	2%
Crappie	0%	50%	0%	0%	0%	1%
Kokanee	0%	0%	57%	50%	16%	47%
Longnose Sucker	0%	0%	0%	0%	0%	0%
Largescale Sucker	0%	50%	0%	0%	0%	1%
N. Pikeminnow	0%	0%	5%	0%	5%	2%
Peamouth	0%	0%	0%	0%	0%	0%
Rainbow Trout	0%	0%	0%	16%	0%	7%
Sculpin	0%	0%	0%	0%	0%	0%
Smallmouth Bass	0%	0%	0%	0%	0%	0%
Sturgeon	0%	0%	0%	0%	5%	2%
Walleye	0%	0%	5%	12%	16%	9%
Lake Whitefish	0%	0%	33%	20%	58%	29%
Yellow Perch	0%	0%	0%	0%	0%	0%

**Table A.3.** Reservoir wide percent species composition by depth for each month. Corrected for bottom encroachment in the upper and middle regions. Uncorrected sample sizes are shown, September excludes 15 fish caught in the mouth of Hawk Creek which were used in the size frequency calculations.

Species	September		
	Depth (m)		
	0-40	40-80	80-120
n=	61	8	12
Burbot	0%	13%	0%
Chinook	0%	0%	0%
Crappie	0%	0%	0%
Kokanee	20%	13%	100%
Longnose Sucker	8%	13%	0%
Largescale Sucker	0%	0%	0%
N. Pikeminnow	2%	0%	0%
Peamouth	2%	0%	0%
Rainbow Trout	7%	0%	0%
Sculpin	25%	0%	0%
Smallmouth Bass	0%	0%	0%
Sturgeon	0%	0%	0%
Walleye	10%	25%	0%
Lake Whitefish	23%	38%	0%
Yellow Perch	5%	0%	0%

Species	October		
	Depth (m)		
	0-40	40-80	80-120
n=	56	36	2
Burbot	0%	0%	0%
Chinook	4%	0%	0%
Crappie	2%	0%	0%
Kokanee	30%	58%	100%
Longnose Sucker	0%	0%	0%
Largescale Sucker	0%	3%	0%
N. Pikeminnow	4%	0%	0%
Peamouth	0%	0%	0%
Rainbow Trout	14%	0%	0%
Sculpin	0%	0%	0%
Smallmouth Bass	0%	0%	0%
Sturgeon	2%	3%	0%
Walleye	16%	3%	0%
Lake Whitefish	29%	33%	0%
Yellow Perch	0%	0%	0%

**Table A.4.** Density for each size class and total density (# / million m<sup>3</sup>) of fish within each transect for September 1998.

Transect	25-100	100-200	200-300	300-400	400-700	Total
L1	49.2	28.5	12.4	8.5	4.4	103.0
L2	38.6	14.8	8.2	4.5	4.5	70.6
L3	59.2	8.1	2.7	2.7	4.1	76.8
M1	3.5	2.1	0.9	0.7	0.4	7.5
M2	10.8	3.4	3.1	1.2	1.5	20.0
M3	7.3	4.3	2.6	3.4	0.7	18.3
M4	34.3	10.8	3.1	1.1	1.2	50.4
M5	12.9	12.6	6.9	1.8	2.4	36.6
M6	7.8	2.7	1.6	1.0	2.0	15.1
M7	51.0	22.8	4.3	1.5	2.2	81.7
M8	77.2	16.7	3.9	0.9	1.6	100.2
U1	6.3	5.4	4.2	1.6	1.9	19.4
U2	3.7	3.4	1.7	1.9	1.1	11.8
U3	14.5	6.7	5.1	1.5	6.4	34.1
U4	41.2	15.3	6.8	6.7	4.2	74.1
U5	91.5	28.3	11.9	9.4	10.6	151.8
mean	31.8	11.6	5.0	3.0	3.1	54.5
SD	27.9	8.9	3.5	2.8	2.6	41.5
95% CI	14.0	4.4	1.7	1.4	1.3	20.8
Coef. of Var.	0.44	0.38	0.35	0.46	0.43	0.38

Table A.5 Density for each size class and total density (# / million m<sup>3</sup>) of fish within each transect for October 1998.

Transect	25-100	100-200	200-300	300-400	400-700	Total
L1	4.3	6.0	9.3	2.3	15.4	37.4
L2	5.7	5.5	0.8	1.0	1.7	14.6
L3	10.6	13.0	4.6	2.4	1.4	32.0
L4	10.2	2.2	1.2	3.1	1.4	18.0
L5	17.0	9.9	3.8	3.7	5.1	39.4
L6	11.4	4.8	3.6	2.8	1.6	24.2
L7	4.5	3.2	1.3	1.3	0.9	11.2
L8	16.5	14.4	9.4	6.9	5.6	52.8
M1	18.0	5.0	5.6	3.0	1.9	33.5
M2	23.4	6.0	6.6	2.3	3.2	41.6
M3	9.1	4.0	1.8	0.8	0.8	16.6
M4	3.5	3.7	2.3	1.7	1.6	12.8
M5	13.8	9.8	5.3	2.0	1.4	32.4
M6	21.6	7.5	3.6	1.9	3.0	37.5
M7	12.1	7.4	3.3	2.0	1.8	26.6
M8	8.9	2.9	5.4	5.2	6.0	28.3
M9	28.1	13.2	14.7	7.3	17.2	80.5
U1	8.7	6.5	4.1	3.6	4.2	27.1
U2	29.1	9.4	6.4	5.4	6.1	56.4
U3	10.1	6.4	6.7	6.1	6.5	35.9
U4	13.8	7.2	8.1	6.3	6.3	41.7
U6	27.2	7.6	4.9	2.2	5.6	47.4
U7	91.8	23.9	7.3	2.9	3.7	129.5
U8	76.2	38.2	8.8	8.6	9.9	141.8
mean	19.8	9.1	5.4	3.5	4.7	42.5
SD	21.2	7.8	3.2	2.2	4.3	32.7
95% CI	8.7	3.2	1.3	0.9	1.8	13.3
Coef. of Var.	0.44	0.35	0.25	0.25	0.37	0.31







# Appendix B

## Bioenergetics Model Inputs

**Table B.1.** Mean wet weight proportion of each diet item converted from dry weights measured by STI for 1996. "Other" category includes other invertebrates, unidentified non-fish prey. Prey codes; Dap = *Daphnia*, Lep = *Leptodora*, Cop = copepods, Ins = insects, Oth = other, Cot = cottids, Cat = catostomids, Cyp = Cyprinids, Cen = centrarchids, Per = percids, Sal = salmonids, Ost = unidentified fish prey.

	Day	n	Dap	Lep	Cop	Ins	Oth	Cot	Cat	Cyp	Cen	Per	Sal	Ost
Kokanee	1	15	0.66	0.21	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	365	15	0.66	0.21	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rainbow	1	56	0.27	0.13	0.00	0.47	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Trout	74	56	0.27	0.13	0.00	0.47	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.03
	135	22	0.00	0.00	0.00	0.76	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.05
	196	13	0.34	0.26	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	288	21	0.51	0.19	0.00	0.20	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.03
	365	56	0.27	0.13	0.00	0.47	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Walleye	1	19	0.00	0.11	0.00	0.09	0.03	0.32	0.05	0.00	0.00	0.00	0.00	0.41
Age 1	365	19	0.00	0.11	0.00	0.09	0.03	0.32	0.05	0.00	0.00	0.00	0.00	0.41
Walleye	1	120	0.01	0.01	0.00	0.15	0.00	0.16	0.03	0.01	0.00	0.07	0.13	0.44
Ages 2-7	90	120	0.01	0.01	0.00	0.15	0.00	0.16	0.03	0.01	0.00	0.07	0.13	0.44
	135	44	0.00	0.03	0.00	0.21	0.00	0.14	0.03	0.00	0.00	0.03	0.08	0.50
	196	51	0.00	0.00	0.00	0.09	0.00	0.14	0.03	0.03	0.00	0.06	0.20	0.46
	288	26	0.03	0.00	0.00	0.16	0.00	0.20	0.04	0.00	0.00	0.16	0.10	0.31
	365	120	0.01	0.01	0.00	0.15	0.00	0.16	0.03	0.01	0.00	0.07	0.13	0.44

**Table B.2.** Mean wet weight proportion of each diet item converted from dry weights measured by STI for 1997. "Other" category includes other invertebrates, unidentified non-fish prey. Prey codes; Dap = *Daphnia*, Lep = *Leptodora*, Cop = copepods, Ins = insects, Oth = other, Cot = cottids, Cat = catostomids, Cyp = Cyprinids, Cen = centrarchids, Per = percids, Sal = salmonids, Ost = unidentified fish prey.

	Day	n	Dap	Lep	Cop	Ins	Oth	Cot	Cat	Cyp	Cen	Per	Sal	Ost
Kokanee	1	21	0.76	0.10	0.06	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	365	21	0.76	0.10	0.06	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rainbow	1	28	0.49	0.20	0.01	0.19	0.05	0.02	0.00	0.00	0.00	0.00	0.04	0.01
Trout	74	28	0.49	0.20	0.01	0.19	0.05	0.02	0.00	0.00	0.00	0.00	0.04	0.01
	152	14	0.29	0.36	0.00	0.21	0.07	0.00	0.00	0.00	0.00	0.00	0.07	0.00
	243	14	0.29	0.36	0.00	0.21	0.07	0.00	0.00	0.00	0.00	0.00	0.07	0.00
	274	10	0.76	0.00	0.02	0.12	0.03	0.04	0.00	0.00	0.00	0.00	0.00	0.02
	365	28	0.49	0.20	0.01	0.19	0.05	0.02	0.00	0.00	0.00	0.00	0.04	0.01
	365	28	0.49	0.20	0.01	0.19	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.04
Walleye	1	9	0.00	0.00	0.00	0.20	0.00	0.29	0.12	0.03	0.00	0.00	0.00	0.35
Age 1	365	9	0.00	0.00	0.00	0.20	0.00	0.29	0.12	0.03	0.00	0.00	0.00	0.35
Walleye	1	91	0.05	0.02	0.00	0.05	0.02	0.20	0.12	0.12	0.02	0.03	0.00	0.38
Ages 2-7	74	91	0.05	0.02	0.00	0.05	0.02	0.20	0.12	0.12	0.02	0.03	0.00	0.38
	152	56	0.05	0.00	0.00	0.08	0.03	0.15	0.13	0.18	0.00	0.02	0.00	0.36
	243	56	0.05	0.00	0.00	0.08	0.03	0.15	0.13	0.18	0.00	0.02	0.00	0.36
	274	33	0.05	0.05	0.00	0.01	0.00	0.27	0.12	0.04	0.04	0.03	0.00	0.40
	365	91	0.05	0.02	0.00	0.05	0.02	0.20	0.12	0.12	0.02	0.03	0.00	0.38
	365	91	0.05	0.02	0.00	0.05	0.02	0.20	0.12	0.12	0.02	0.03	0.00	0.38
Whitefish	1	6	0.49	0.00	0.00	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	365	6	0.49	0.00	0.00	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Northern	1	21	0.00	0.00	0.00	0.06	0.61	0.00	0.03	0.00	0.00	0.06	0.17	0.07
Pikeminnow	365	21	0.00	0.00	0.00	0.06	0.61	0.00	0.03	0.00	0.00	0.06	0.17	0.07
Burbot	1	34	0.00	0.02	0.00	0.19	0.08	0.32	0.00	0.05	0.00	0.00	0.00	0.34
	74	34	0.00	0.02	0.00	0.19	0.08	0.32	0.00	0.05	0.00	0.00	0.00	0.34
	152	15	0.00	0.04	0.00	0.20	0.00	0.36	0.00	0.02	0.00	0.00	0.00	0.38
	243	15	0.00	0.04	0.00	0.20	0.00	0.36	0.00	0.02	0.00	0.00	0.00	0.38
	274	19	0.00	0.00	0.00	0.19	0.15	0.29	0.00	0.06	0.00	0.00	0.00	0.31
	365	34	0.00	0.02	0.00	0.19	0.08	0.32	0.00	0.05	0.00	0.00	0.00	0.34
	365	34	0.00	0.02	0.00	0.19	0.08	0.32	0.00	0.05	0.00	0.00	0.00	0.34
Smallmouth	1	14	0.00	0.00	0.00	0.10	0.03	0.33	0.05	0.00	0.08	0.08	0.00	0.32
Bass	365	14	0.00	0.00	0.00	0.10	0.03	0.33	0.05	0.00	0.08	0.08	0.00	0.32



Table B.4.1. Thermal experience for kokanee, rainbow trout, and walleye in 1996. Thermal experience was selected as the closest available temperature to the growth optimum for each age class.

Julian Day	Kokanee				Rainbow trout					
	Age				Age					
	0	1	2	3	0	1	2	3	4	5
1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4	4.0
15	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
46	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
74	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
105	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
135	12.5	12.5	12.5	11.5	12.5	12.5	12.5	12.5	13	12.0
166	15.5	14.0	13.0	11.5	15.5	15.5	13.5	13.0	13	12.0
196	17.0	14.0	13.0	11.5	18.0	16.5	13.5	13.0	13	12.8
227	17.0	13.4	13.0	11.5	18.0	16.5	13.5	13.4	13	13.4
258	17.0	14.2	13.0	11.5	18.0	16.5	14.2	14.2	14	14.2
288	15.8	14.0	13.0	11.5	15.8	15.8	13.5	13.0	13	13.0
319	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12	12.0
349	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
365	4.0	4.0	4.0	4.0	4	4	4	4	4	4.0

	Walleye							
	Age							
	0	1	2	3	4	5	6	7
1	na	4.0	4.0	4.0	4	4	4.0	4.0
15	na	3.5	3.5	3.5	3.5	3.5	3.5	3.5
46	na	3.5	3.5	3.5	3.5	3.5	3.5	3.5
74	na	3.5	3.5	3.5	3.5	3.5	3.5	3.5
105	na	7.5	7.5	7.5	7.5	7.5	7.5	7.5
135	na	12.5	12.5	12.5	12.5	12.5	12.5	12.5
166	na	15.5	15.5	15.5	15.5	15.5	15.5	15.0
196	na	20.6	17.5	17.0	16.5	16	15.5	15.0
227	na	22.0	17.5	17.0	16.5	16	15.5	15.0
258	na	19.4	17.5	17.0	16.5	16	15.5	15.0
288	na	15.8	15.8	15.8	15.8	15.8	15.5	15.0
319	na	12.3	12.3	12.3	12.3	12.3	12.3	12.3
349	na	5.3	5.3	5.3	5.35	5.35	5.3	5.3
365	na	4	4	4	4	4	4	4

**Table B.4.2.** Thermal experience used in the bioenergetics model for kokanee in 1997. Thermal experience was selected as the closest available temperature to the growth optimum for each age class.

Julian Day	Age				Julian Day	Age			
	0	1	2	3		0	1	2	3
1	3.1	3.1	3.1	3.1	216	16.8	16.8	16.8	16.8
14	3.1	3.1	3.1	3.1	217	14.5	14.6	14.6	14.6
15	2.5	2.5	2.5	2.5	218	16.1	16.1	16.1	16.1
42	2.8	2.8	2.8	2.8	230	18.1	18.1	18.1	18.1
50	1.9	1.9	1.9	1.9	231	17.9	17.9	17.9	17.9
71	4.2	4.2	4.2	4.2	232	18.1	18.1	18.1	18.1
72	3.4	3.4	3.4	3.4	245	18.1	18.1	18.1	18.1
86	5.9	5.9	5.9	5.9	246	17.1	17.1	17.1	17.1
87	4.2	4.2	4.2	4.2	247	17.7	17.7	17.7	17.7
90	4.7	4.7	4.7	4.7	259	17.9	17.9	17.9	17.9
107	6.1	6.1	6.1	6.1	260	15.8	15.8	15.8	15.8
132	10.5	10.5	10.5	10.5	261	18.3	18.3	18.3	18.3
133	13.9	13.0	12.5	11.5	265	15.2	15.2	15.2	15.2
134	11.4	11.4	11.4	11.4	272	16.6	16.6	16.6	16.6
135	10.1	10.1	10.1	10.1	273	14.5	14.4	14.4	14.4
148	10.4	10.4	10.4	10.4	274	17.4	17.4	17.4	17.4
149	14.0	13.0	12.5	11.5	275	17.7	17.7	17.7	17.7
155	13.0	13.0	12.5	11.5	286	14.5	14.0	14.0	14.0
162	14.5	13.0	12.5	11.5	288	13.4	13.0	12.5	12.0
163	13.5	13.0	12.5	11.7	289	15.1	15.1	15.1	15.1
164	12.2	12.2	12.2	11.9	300	14.5	13.9	13.9	13.9
174	13.1	13.0	12.8	12.8	301	11.4	10.7	10.7	11.4
176	14.5	13.0	13.5	13.5	302	13.4	13.0	12.5	11.7
178	14.5	13.0	12.8	12.8	303	12.5	12.5	12.5	12.0
188	14.5	13.0	13.8	13.8	321	10.5	10.5	10.5	10.5
189	14.9	14.9	14.9	14.9	322	11.8	11.8	11.8	11.5
191	14.5	14.5	14.5	14.5	323	8.4	8.4	8.4	8.4
196	14.5	13.9	13.9	13.9	355	5.5	5.5	5.5	5.5
202	14.5	13.7	13.7	13.7	356	5.2	5.2	5.2	5.2
203	15.1	15.1	15.1	15.1	357	6.3	6.3	6.3	6.3
204	15.1	15.1	15.1	15.1	365	3.1	3.1	3.1	3.1

**Table B.4.3.** Thermal experience used in the bioenergetics model for rainbow trout in 1997. Thermal experience was selected as the closest available temperature to the growth optimum for each age class.

Julian Day	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Julian Day	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5
1	3.1	3.1	3.1	3.1	3.1	3.1	216	16.8	16.8	16.8	16.8	16.8	16.8
14	3.1	3.1	3.1	3.1	3.1	3.1	217	14.6	14.6	14.6	14.6	14.6	14.6
15	2.5	2.5	2.5	2.5	2.5	2.5	218	16.1	16.1	16.1	16.1	16.1	16.1
42	2.8	2.8	2.8	2.8	2.8	2.8	230	18.1	18.1	18.1	18.1	18.1	18.1
50	1.9	1.9	1.9	1.9	1.9	1.9	231	17.9	17.9	17.9	17.9	17.9	17.9
71	4.2	4.2	4.2	4.2	4.2	4.2	232	18.1	18.1	18.1	18.1	18.1	18.1
72	3.4	3.4	3.4	3.4	3.4	3.4	245	18.1	18.1	18.1	18.1	18.1	18.1
86	5.9	5.9	5.9	5.9	5.9	5.9	246	17.1	17.1	17.1	17.1	17.1	17.1
87	4.2	4.2	4.2	4.2	4.2	4.2	247	17.7	17.7	17.7	17.7	17.7	17.7
90	4.7	4.7	4.7	4.7	4.7	4.7	259	17.9	17.9	17.9	17.9	17.9	17.9
107	6.1	6.1	6.1	6.1	6.1	6.1	260	15.8	15.8	15.8	15.8	15.8	15.8
132	10.5	10.5	10.5	10.5	10.5	10.5	261	18.3	18.3	18.3	18.3	18.3	18.3
133	12.5	11.5	13.0	13.0	12.5	11.5	265	15.2	15.2	15.2	15.2	15.2	15.2
134	11.4	11.4	11.4	11.4	11.4	11.4	272	16.6	16.6	16.6	16.6	16.6	16.6
135	10.1	10.1	10.1	10.1	10.1	10.1	273	14.4	14.4	14.4	14.4	14.4	14.4
148	10.4	10.4	10.4	10.4	10.4	10.4	274	17.4	17.4	17.4	17.4	17.4	17.4

149 12.5 11.5 13.0 13.0 12.5 12.0 275 17.7 17.7 17.7 17.7 17.7 17.7  
 155 12.5 11.5 13.0 13.0 12.5 12.0 286 14.0 14.0 14.0 14.0 14.0 14.0  
 162 12.5 11.5 13.0 13.0 12.5 12.0 288 12.5 13.4 13.0 13.0 12.5 12.0  
 163 12.5 11.7 13.0 13.0 12.5 12.0 289 15.1 15.1 15.1 15.1 15.1 15.1  
 164 12.2 11.9 12.2 12.2 12.2 12.0 300 13.9 14.0 13.9 13.9 13.9 13.9  
 174 12.8 12.8 13.0 13.0 12.8 12.8 301 10.7 11.4 10.7 10.7 10.7 11.4  
 176 13.5 14.0 13.0 13.0 13.5 13.5 302 12.5 13.4 13.0 13.0 12.5 12.0  
 178 12.8 14.0 13.0 13.0 12.8 12.8 303 12.5 12.5 12.5 12.5 12.5 12.0  
 188 13.8 14.0 13.0 13.0 13.8 12.0 321 10.5 10.5 10.5 10.5 10.5 10.5  
 189 14.9 14.9 14.9 14.9 14.9 14.9 322 11.8 11.8 11.8 11.8 11.8 11.8  
 191 14.5 14.5 14.5 14.5 14.5 14.5 323 8.4 8.4 8.4 8.4 8.4 8.4  
 196 13.9 14.0 13.9 13.9 13.9 13.9 355 5.5 5.5 5.5 5.5 5.5 5.5  
 202 13.7 14.0 13.7 13.7 13.7 13.7 356 5.2 5.2 5.2 5.2 5.2 5.2  
 203 15.1 15.1 15.1 15.1 15.1 15.1 357 6.3 6.3 6.3 6.3 6.3 6.3  
 204 15.1 15.1 15.1 15.1 15.1 15.1 365 3.1 3.1 3.1 3.1 3.1 3.1

63

Table B.4.4 Thermal experience used in the bioenergetics model for walleye in 1997. Thermal experience was selected as the closest available temperature to the growth optimum for each age class.

Julian Age	Julian Age	Day 1	2	3	4	5	6	7	Day 1	2	3	4	5	6	7
1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	216	19.9	17.5	17.0	16.8	16.8	16.8
14	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	217	23.0	17.5	17.0	16.5	16.0	15.5
15	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	218	23.0	17.5	17.0	16.5	16.1	16.1
42	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	230	22.4	18.1	18.1	18.1	18.1	18.1
50	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	231	22.7	17.9	17.9	17.9	17.9	17.9
71	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	232	22.4	18.1	18.1	18.1	18.1	18.1
72	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	245	21.6	18.1	18.1	18.1	18.1	18.1
86	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	246	18.6	17.5	17.1	17.1	17.1	17.1
87	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	247	20.3	17.7	17.7	17.7	17.7	17.7
90	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	259	18.9	17.9	17.9	17.9	17.9	17.9
107	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	260	17.0	17.0	17.0	16.5	16.0	15.8
132	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	261	18.8	18.3	18.3	18.3	18.3	18.3
133	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	265	16.7	16.7	16.7	16.5	15.2	15.2
134	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	272	18.1	17.5	17.0	16.6	16.6	16.6
135	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	273	16.3	16.3	16.3	16.3	16.0	15.5
148	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	274	17.9	17.5	17.4	17.4	17.4	17.4
149	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	275	17.8	17.7	17.7	17.7	17.7	17.7
155	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	286	15.8	15.8	15.8	15.8	15.5	15.0
162	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	288	13.4	13.4	13.4	13.4	13.4	13.4
163	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	289	16.0	16.0	16.0	16.0	15.5	15.1
164	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	300	14.6	14.6	14.6	14.6	14.6	14.6
174	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	301	11.4	11.4	11.4	11.4	11.4	11.4
176	15.3	15.3	15.3	15.3	15.3	15.3	15.0	15.0	302	13.4	13.4	13.4	13.4	13.4	13.4
178	17.0	17.0	17.0	16.5	16.0	15.5	15.0	15.0	303	12.5	12.5	12.5	12.5	12.5	12.5
188	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	321	10.5	10.5	10.5	10.5	10.5	10.5
189	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	322	11.8	11.8	11.8	11.8	11.8	11.8
191	15.3	15.3	15.3	15.3	15.3	15.3	15.0	15.0	323	8.4	8.4	8.4	8.4	8.4	8.4
196	22.3	17.5	17.0	16.5	16.5	15.5	15.0	15.0	355	5.5	5.5	5.5	5.5	5.5	5.5
202	23.0	17.5	17.0	16.5	16.5	15.5	15.0	15.0	356	5.2	5.2	5.2	5.2	5.2	5.2
203	17.0	17.0	17.0	16.5	16.5	15.5	15.1	15.1	357	6.3	6.3	6.3	6.3	6.3	6.3
204	21.2	17.5	17.0	16.5	16.5	15.5	15.1	15.1	365	3.1	3.1	3.1	3.1	3.1	3.1

64

Table B.4.5 Thermal experience used in the bioenergetics model for whitefish in 1997. Thermal experience was selected as the closest available temperature to the growth optimum for each age class.



155	13.0	13.0	13.0	13.0	13.0	13.0	13.0	286	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8
162	14.7	14.7	14.7	14.7	14.7	14.7	14.7	288	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4
163	13.5	13.5	13.5	13.5	13.5	13.5	13.5	289	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
164	12.2	12.2	12.2	12.2	12.2	12.2	12.2	300	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
174	13.1	13.1	13.1	13.1	13.1	13.1	13.1	301	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4
176	15.3	15.3	15.3	15.3	15.3	15.3	15.3	302	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4
178	17.0	17.0	17.0	17.0	17.0	17.0	17.0	303	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
188	14.9	14.9	14.9	14.9	14.9	14.9	14.9	321	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
189	14.9	14.9	14.9	14.9	14.9	14.9	14.9	322	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
191	15.3	15.3	15.3	15.3	15.3	15.3	15.3	323	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
196	20.0	19.0	19.0	18.5	18.5	18.0	18.0	355	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
202	20.0	19.0	19.0	18.5	18.5	18.0	18.0	356	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
203	17.0	17.0	17.0	17.0	17.0	17.0	17.0	357	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
204	20.0	19.0	19.0	18.5	18.5	18.0	18.0	365	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1

66

Table B.4.7 Thermal experience used in the bioenergetics model for burbot in 1997. Thermal experience was selected as the closest available temperature to the growth optimum for each age class.

Julian Age Julian Age

Day 1 2 3 4 5 6 7 Day 1 2 3 4 5 6 7

1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	216	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8
14	3.1	3.1	3.1	3.1	3.1	3.1	3.1	217	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
15	2.5	2.5	2.5	2.5	2.5	2.5	2.5	218	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
42	2.8	2.8	2.8	2.8	2.8	2.8	2.8	230	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
50	1.9	1.9	1.9	1.9	1.9	1.9	1.9	231	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9
71	4.2	4.2	4.2	4.2	4.2	4.2	4.2	232	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
72	3.4	3.4	3.4	3.4	3.4	3.4	3.4	245	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
86	5.9	5.9	5.9	5.9	5.9	5.9	5.9	246	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1
87	4.2	4.2	4.2	4.2	4.2	4.2	4.2	247	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7
90	4.7	4.7	4.7	4.7	4.7	4.7	4.7	259	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9
107	6.1	6.1	6.1	6.1	6.1	6.1	6.1	260	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8
132	10.5	10.5	10.5	10.5	10.5	10.5	10.5	261	18.3	18.3	18.3	18.3	18.3	18.3	18.3	18.3
133	13.9	13.9	13.9	13.9	13.9	13.9	13.9	265	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2
134	11.4	11.4	11.4	11.4	11.4	11.4	11.4	272	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6
135	10.1	10.1	10.1	10.1	10.1	10.1	10.1	273	15.0	14.5	14.5	14.5	14.5	14.5	14.5	14.5
148	10.4	10.4	10.4	10.4	10.4	10.4	10.4	274	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4
149	14.0	14.0	14.0	14.0	14.0	14.0	14.0	275	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7
155	13.0	13.0	13.0	13.0	13.0	13.0	13.0	286	15.0	14.5	14.5	14.0	14.0	14.0	14.0	14.0
162	14.7	14.5	14.5	14.5	14.5	14.5	14.5	288	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4
163	13.5	13.5	13.5	13.5	13.5	13.5	13.5	289	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
164	12.2	12.2	12.2	12.2	12.2	12.2	12.2	300	14.6	14.5	14.5	14.0	14.0	14.0	14.0	14.0
174	13.1	13.1	13.1	13.1	13.1	13.1	13.1	301	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4
176	15.0	14.5	14.5	14.0	14.0	14.0	14.0	302	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4
178	15.0	14.5	14.5	14.0	14.0	14.0	14.0	303	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
188	14.9	14.5	14.5	14.0	14.0	14.0	14.0	321	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
189	14.9	14.9	14.9	14.9	14.9	14.9	14.9	322	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
191	15.0	14.5	14.5	14.5	14.5	14.5	14.5	323	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
196	15.0	14.5	14.5	14.0	14.0	14.0	14.0	355	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
202	15.0	14.5	14.5	14.0	14.0	14.0	14.0	356	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
203	15.1	15.1	15.1	15.1	15.1	15.1	15.1	357	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
204	15.1	15.1	15.1	15.1	15.1	15.1	15.1	365	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1

67

Table B.4.8 Thermal experience used in the bioenergetics model for smallmouth bass in 1997. Thermal experience was selected as the closest available temperature to the growth optimum for each age class.

Age Age

Julian Day 0 1 2 3 4 5 Julian Day 0 1 2 3 4 5  
1 3.1 3.1 3.1 3.1 3.1 3.1 216 19.9 19.9 19.9 19.9 19.9 19.9  
14 3.1 3.1 3.1 3.1 3.1 3.1 217 23.9 23.9 23.9 23.9 23.9 23.9  
15 2.5 2.5 2.5 2.5 2.5 2.5 218 23.7 23.7 23.7 23.7 23.7 23.7  
42 2.8 2.8 2.8 2.8 2.8 2.8 230 22.4 22.4 22.4 22.4 22.4 22.4  
50 1.9 1.9 1.9 1.9 1.9 1.9 231 22.7 22.7 22.7 22.7 22.7 22.7  
71 4.2 4.2 4.2 4.2 4.2 4.2 232 22.4 22.4 22.4 22.4 22.4 22.4  
72 3.4 3.4 3.4 3.4 3.4 3.4 245 21.6 21.6 21.6 21.6 21.6 21.6  
86 5.9 5.9 5.9 5.9 5.9 5.9 246 18.6 18.6 18.6 18.6 18.6 18.6  
87 4.2 4.2 4.2 4.2 4.2 4.2 247 20.3 20.3 20.3 20.3 20.3 20.3  
90 4.7 4.7 4.7 4.7 4.7 4.7 259 18.9 18.9 18.9 18.9 18.9 18.9  
107 6.1 6.1 6.1 6.1 6.1 6.1 260 17.0 17.0 17.0 17.0 17.0 17.0  
132 10.5 10.5 10.5 10.5 10.5 10.5 261 18.8 18.8 18.8 18.8 18.8 18.8  
133 13.9 13.9 13.9 13.9 13.9 13.9 265 16.7 16.7 16.7 16.7 16.7 16.7  
134 11.4 11.4 11.4 11.4 11.4 11.4 272 18.1 18.1 18.1 18.1 18.1 18.1  
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162 14.7 14.7 14.7 14.7 14.7 14.7 288 13.4 13.4 13.4 13.4 13.4 13.4  
163 13.5 13.5 13.5 13.5 13.5 13.5 289 16.0 16.0 16.0 16.0 16.0 16.0  
164 12.2 12.2 12.2 12.2 12.2 12.2 300 14.6 14.6 14.6 14.6 14.6 14.6  
174 13.1 13.1 13.1 13.1 13.1 13.1 301 11.4 11.4 11.4 11.4 11.4 11.4  
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196 22.3 22.3 22.3 22.3 22.3 22.3 355 5.5 5.5 5.5 5.5 5.5 5.5  
202 23.9 23.9 23.9 23.9 23.9 23.9 356 5.2 5.2 5.2 5.2 5.2 5.2  
203 17.0 17.0 17.0 17.0 17.0 17.0 357 6.3 6.3 6.3 6.3 6.3 6.3  
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